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Research Article

Application of Spatial-Temporal Behavioral Trajectory Analysis in the Space Design of Digital Villages

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From the perspective of the environment-behavior science, this paper takes the space design of a digital village in Youzhaqiao Village on the outskirts of Guangshui City, for example, to record and track the behavior of residents and tourists in the area via mobile phone motion track recording software. Based on the collection, selection, and collation of the trajectory data, the valid data has been counted and analyzed; finally, the field investigation and questionnaires have been integrated to propose optimization strategy for the use and design of the space of Youzhaqiao Village from aspects such as human perception, cognition, and behavior.

1. Introduction

An important part of achieving rural modernization is the steady advancement of digitization and the sustainable vitalization of the traditional countryside. In particular under the situation where smart cities, IT applications, and intelligent technologies are constantly being promoted, the scope of rural space design has been greatly widened by the strategies of integration of digital village and smart agriculture, providing strong momentum to rural tourism planning and opening up a new economic situation of urban-rural integration and digitization development as well [1]. This paper will study how the intelligent technology and behavioral trajectory data can be integrated into the rural space design.

From the perspective of the environment-behavior science, this paper takes the space design of a digital village in Youzhaqiao Village on the outskirts of Guangshui City, for example, to record and track the behavior and activity of residents and tourists in the area via mobile phone motion track recording software. Based on the collection, selection, and collation of the trajectory data, the valid data has been counted and analyzed; finally, the field investigation and questionnaires have been integrated to propose an optimization strategy for the use and design of the space of Youzhaqiao Village from aspects such as human perception, cognition, and behavior.

2. Research Background and Significance

2.1. Research Background. An important part of achieving rural modernization is the steady advancement of digitization and the sustainable vitalization of the traditional countryside. In particular under the situation where smart cities, IT applications, and intelligent technologies are constantly being promoted, the scope of rural space design has been greatly widened by the strategies of integration of digital village and smart agriculture, providing strong momentum to rural tourism planning and opening up a new economic situation of urban-rural integration and digitization development as well [1]. This paper will study how the intelligent technology and behavioral trajectory data can be integrated into the rural space design.

With villages as a vital and inseparable part of the country, rural revitalization and rural tourism are inextricably linked, while the planning and designing of rural tourism are unique from other types of planning and designing which need to consider the sustainability of agricultural development and rural landscape layout under the premise of sound rural function and reasonable industrial layout. And the rapid development of intelligent terminals and location-based services (LBS) and smart terminals led by GPS navigators and smartphone apps (especially sports

and health categories) not only facilitates the public's travel but also provides data support for the study of spatial-temporal behavior patterns [2].

The analysis of tourists' behavioral characteristics is one of the most important bases for landscape design. Compared with field investigation and questionnaires, which are the most widely used methods of information collection, the spatial-temporal behavioral trajectory analysis has more advantageous continuity and accuracy in respect of time and space, better reflecting the tourists' behavioral features. The spatial-temporal behavioral trajectories of experimental subjects can be collected via the recording data of these subjects' GPS, which have been combined with the time geography to compute and visualize human behavior patterns geographically by scholars such as Guan et al. [2]. As for the vast tourist GPS data, foreign scholars such as Orellana et al. have proposed to analyze the data with both MSPs (Movement Suspension Patterns) and GSPs (Generalized Sequential Patterns), while MSPs represent places where tourists stop moving for interests and GSPs represent the general time order of places visited by tourists [3]. Huang and other scholars have utilized ArcGIS technology to realize three-dimensional visualization of space-time route from GPS track points, evaluating and analyzing the length of route, time, speed, and coverage of sightseeing. And combining the concept of space-time-route theory with two-pole emotions of tourism experience model, they also have proposed a concept of "Tourism Emotional Path" (TEP) to study the black box of tourists' emotions in their tourism experience [4].

From the perspective of the environment-behavior science, this paper takes the space design of a digital village in Youzhaqiao Village on the outskirts of Guangshui City, for example, to record and track the behavior and activity of residents and tourists in the area via mobile phone motion track recording software. Based on the collection, selection, and collation of the trajectory data, the valid data has been counted and analyzed; finally, the field investigation and questionnaires have been integrated to propose an optimization strategy for the use and design of the space of Youzhaqiao Village from aspects such as human perception, cognition, and behavior.

2.2. Research Significance

2.2.1. It Has Practical Guiding Significance for the Spatial Layout of Rural Tourism. Through the analysis of the spatial characteristics and dilemmas of rural tourism and the feasibility analysis of digital applications, empirical cases are studied, and typical spatial planning models are extracted, which provides important technical support and practical reference for the formulation of digital rural spatial development strategies and policies in Hubei Province. Based on this, it has the following three practical guiding significances: first, guide local governments to effectively manage the use of rural tourism resources, scientifically guide the layout of rural tourism landscapes, and promote the construction of a digital rural tourism system; second, provide references for the design of policies and systems for rural tourism spatial planning in Hubei Province; and third, provide technical and methodological support for the preparation of rural planning in Hubei Province.

2.2.2. Provide Technical Support for Improving Digital Rural Tourism Planning. Innovatively integrating spatio-temporal behavior trajectory data analysis technology into rural tourism spatial planning and solving its compatibility problem will significantly enhance the application value of digital technology in rural lagging areas, highlight its basic supporting role for the optimization of rural tourism space layout, and further improve the accuracy and appropriateness of digital rural tourism space planning strategies, which has strong practicality.

2.2.3. Explore and Improve the Optimization Path of Digital Rural Tourism Spatial Layout. Based on multiple elements, this paper accurately identifies the spatial characteristics and spatial distribution law of rural tourism and clearly captures the landscape structure, functional distribution, behavior analysis, development direction, and tourist agglomeration effect of rural tourism.

3. Analysis of the Current Space Situation in Youzhaqiao Village

3.1. Advantages

3.1.1. Excellent Transportation Accessibility. Roads pass through the village within the 10-minute reach of the urban area of Yingshan City, which is feasible for one-day tour line.

3.1.2. Beautiful Natural Landscape. Ponds and hillocks are surrounded by lucid waters and lush mountains, which are the foundation for the development of leisure and sightseeing agriculture and rural tourism.

3.1.3. Rich in Cultural Sites. The existing well-protected cultural and historical resources include the old paths of the Tea Horse Road, the old-style private school site, and the old battlefield site of the New Fourth Army and the traditional edible oil extracting workshop.

3.2. Disadvantages

3.2.1. Disorganized Layout of Farm Houses. Youzhaqiao Village has many natural winding roads, with ordinary farmhouses scattered around which are various in building time and style. There exists interference between the daily life of villagers and the tour routes of tourists.

3.2.2. Narrow and Limited Space in This Village. The layout of the farm settlements is rather haphazard, the villagers' farmhouses are located with small spaces between each other, and there are sloppily built-up buildings, which make scarce land available for construction for rest and relaxing, landscape installations, or fitness facilities.

3.2.3. Public Service Facilities, such as Toilets and Other Infrastructure Facilities, Need to Be Improved. Village roads need widening and upgrading because insufficient traffic capacity and low road grade, recreational areas and activity centers, and tourism support services should be supplemented.

3.3. Principles of Digital Rural Space Construction Compared with Other Regions. Villages have their own ecosystems, but this environmental carrying capacity is low, and environmental quality is susceptible to natural and human factors. Therefore, the antidisturbance ability of the ecosystem in ecologically fragile areas is weak; the environmental quality and ecological balance are more susceptible to extensive management behavior, while the sustainable development of rural tourism is to maintain the sustainable use of tourism resources and ecological balance [5], so the sustainable development of rural tourism in this area is more likely to be affected by extensive management behaviors, and the development concept and business methods are more measurable for the sustainable development of rural tourism in the region. According to this, more relevant research and measurement indicators highlight the impact of geomorphological climate, development concept, and operation modes on the sustainable development of rural tourism in ecologically fragile areas and pay more attention to geomorphological and climatic characteristics, tourism resources, etc.: the measurement of sustainable development of rural tourism in ecologically fragile areas and the analysis of influencing factors such as climate and geology. Conditions, quality of tourism resources, degree of regional cultural display, tourism experience, etc.

4. The Common Tools of Environment Spatio-Temporal Behavior Research

As China's urban construction gradually turns to the stock era, planning and design have new requirements for research tools and analysis methods. The traditional research process mainly adopts observation, photography, interview, questionnaire, and manual counting, which is not only difficult to record data with low accuracy and strong subjectivity but also costs a lot of energy in the subsequent analysis. In the era of big data, a number of fast and convenient intelligent research tools have gradually emerged. This paper will introduce a comprehensive tool of track recording in the investigation of environment spatio-temporal behavior [6].

Trajectory data is the data information obtained by sampling the movement process of one or more moving objects in the space-time environment, including the location, sampling time and speed of sampling points, etc., which constitute the trajectory data according to the sequence of sampling. For example, for smart phones with positioning function, the track data reflects the mobile phone holder's action status in a certain period of time. Mobile Internet can locate the location of the phone through wireless signals and then sample and record and form the mobile phone holder's movement track data by connecting the sampling points. GPS positioning terminals can also collect trajectory data [6].

By processing the track data in ArcGIS, the core density of human flow, residence time, and average speed can be analyzed. Among them, the average trajectory speed can reflect the comfort or landscape attraction, and the average trajectory stay time can reflect the activity attraction [6].

5. Research Method Based on Spatial-Temporal Behavior Trajectory

5.1. The Acquisition of Spatial-Temporal Behavior Trajectory. With the spatial temporal behavior trajectory, the main research and analysis method of this paper, we have invited tourists and local volunteers to record their behavioral trajectories by using the mobile phone app and collected and filed the data as GPX formatted trajectory files, from which we have obtained the basic information about their behaviors, including walking path length, walking speed, traveling time, and staying position. We then import the files into processing software such as ArcGIS and then overlay and classify multiple data to finally conduct behavioral pattern analysis. Our train of thought in spatial-temporal behavioral trajectory analysis is as follows.

5.1.1. Comparative Analysis of the Spatial-Temporal Behavior Trajectory of Tourists and Residents. Firstly, we collect and analyze the behavioral trajectories of tourists and residents separately to find the contradictions in spatial use between them. Taking Youzhaqiao Village as an example, we search for contradictions and propose corresponding optimization strategies and then put forward a purposeful landscape design based on the contradictions and optimization strategies.

5.1.2. Analysis of the Most Beautiful Tourist Route. After resolving the contradictions in spatial use between residents and tourists, we analyze the spatial and temporal behavioral trajectories of tourists, paying particular attention to the most traveled routes and the most visited areas, combining this with questionnaires to collect information on the history and culture of local attractions and the location of scenic spots which is worth to visit. In the case of Youzhaqiao Village, we recommend the most beautiful tour routes for tourists.

5.1.3. Analysis of Categorical Planning and Tourism Design. We categorize the tourists from an age perspective, referring to the three age groups proposed by the WHO (World Health Organization), namely, young people under 44, middle-aged people between 45 and 59, and older people over 60. Based on this, we have analyzed the characteristics of each age group and the route of their spatial and temporal behavior and have developed different types of tourism designs for different age groups.

5.2. Questionnaires and Field Investigation. Questionnaires and field investigation are one of the most important information collection methods for tourism landscape design, and the results collected by this method will be used as a subjective supplement in this paper to make up for the defects of spatial-temporal behavior trajectory data in terms of human history and local condition. Therefore, questionnaires and field investigation are used to collect data on the daily life, age distribution, history, culture, and folk customs of the residents of Youzhaqiao Village. A total 200 questionnaires were distributed, and 188 valid questionnaires were recovered (as shown in Table 1). By combining

Table 1: Behavior analysis table of Youzhaqiao Village.

Statistical analysis of behavior types in Youzhaqiao Village	The number	The proportion
Take a rest	15	7%
Pass by	25	13.2%
Leisure and entertainment	22	11.7%
Experience local customs	38	20.2%
Visit cultural and historical sites	25	13.2%
Sightseeing orchard tea garden	35	18.6%
Repast	22	11.7%

the spatial-temporal behavioral trajectories of the residents, we are able to analyze the local conditions in Youzhaqiao Village more thoroughly and thus design and formulate subjective optimization strategies from an objective perspective based on the trajectories.

5.3. Data Sources. The questionnaire set up 14 statistical variables, in line with the principle of being representative, evaluable, and easy to answer, from October 10 to 18, 2019, in the Guangshui oil and oil bridge village tourist site and the location of government departments, in the form of in-depth interview presurvey, with the village tourism operators and managers to demonstrate, after the questionnaire is improved, from October 19, 2019, to August 25, 2020, in the case of rural tourism, in the form of field distribution of questionnaires to investigate. A total of 188 valid questionnaires and 12 invalid questionnaires were collected, and the effective questionnaire rate was 94%, including 140 tourists, 30 rural tourism operators, and 10 rural tourism managers *74.4% of tourists, 21.5% of operators, and 6.6% of managers, respectively). The data of the valid questionnaire were collected, and the data of the two variables that were not related to the sustainable development indicators of rural tourism in the case area were excluded, and the remaining data were valid data, and the valid data were the data sources of the empirical analysis.

6. Analysis of Spatial-Temporal Behavior Trajectory Data in Youzhaqiao Village

6.1. Paradoxical Analysis of Residents and Tourists' Behavior Trajectories. We have collected 200 pieces of information on the spatial-temporal behavioral trajectories of tourists and local residents, respectively, through the smart terminal of the mobile phone app. According to their spatial distribution characteristics, before getting the road planning, it can be seen from the picture in Figure 1 that tourists have a long time to stay at the entrance of the village due to the limited public car parks and the insufficient width of the roads in the village, as well as the insufficient number of public toilets and long waiting times (as shown in Figure 1).

In tea plantations and orchard areas, the spatial-temporal behavioral trajectories of residents and tourists frequently intersect, where the contradiction in spatial use is most serious. We also observe that in the residents' questionnaires and field investigation, pig and cattle farming in the village is predominantly free range, which has led to a disorganized spatial-temporal behavioral trajectory for the residents. In the areas where the residents live and work, tourists pick, trample, and destroy crops at will, causing some damage to the environment of the cultivated farms (Figure 2). As for the above-mentioned areas including the ancient tea horse paths, they are within the essential routes to tourist attractions where tourists stay for a long time. Therefore, the most serious contradictory impacts are on the areas of tea plantations and orchards, for which spatial optimization and guidance measures are proposed.

6.2. Countermeasures for Contradictory Space Optimization. We have planned ecological public car parks in separate points to alleviate the parking demand of tourists and to renovate the motorways in the village. Focusing on renovating and upgrading space between lotus and tea plantations, we suggest transforming the mountainous area into a multi-functional sightseeing tea gardens and orchards, building a spatial pattern where agricultural production keeps pace with tourism. In addition, we choose the hillside land far from the village and water system to build a centralized farming area and build the sewage system.

6.3. Analysis of the Best Tour Route. The best tour route is recommended by considering three aspects: firstly, the attractiveness calculated by the density of tourists' trajectories; secondly, the degree of attraction of the scenic spots along the route; and thirdly, the length of the tour route, meaning that tourists can spend a limited amount of time appreciating more beautiful spots. Combining the overall geographically spatial distribution of the village, the distribution of the main historical and cultural attractions, and the most prevailing trajectory of tourists, we recommend taking the "one axis, two zones" of the leisure and tourism agricultural structure for tourism. The axis is the transportation development axis (the ancient Tea Horse Road), linking the two sides of Shima Road and being the main traffic axis for the development of modern agricultural industry in Youzhaqiao Village. The two zones are the recreational agriculture zone and the space lotus zone. Through experiments, we can find the best tour route, which can fully reflect the comprehensive effect of nature, ecology, and environment, combining agricultural production with science, education, agricultural experience, and tourism in a scientific way and giving visitors multiple choices (as shown in Figure 3).

Rural tourism scenic spots often have many scenic spots, large regional areas, and complex routes in the area; among the many attractions in the village, choose a satisfactory tourist route, so that tourists can visit at the time; the cost and the tourism experience can be satisfied, which is a problem that tourists expect and scenic planners and managers are studying. Based on the thinking of this problem, the system will collect the relevant registration information of the user (age, gender, hobbies, things, city, etc.) data, using the background server to recommend the analysis of the algorithm rational, accurate to provide tourists with reasonable tourism routes. Using this method can both allow tourists to avoid travel at peak of the crowd, save travel time, see

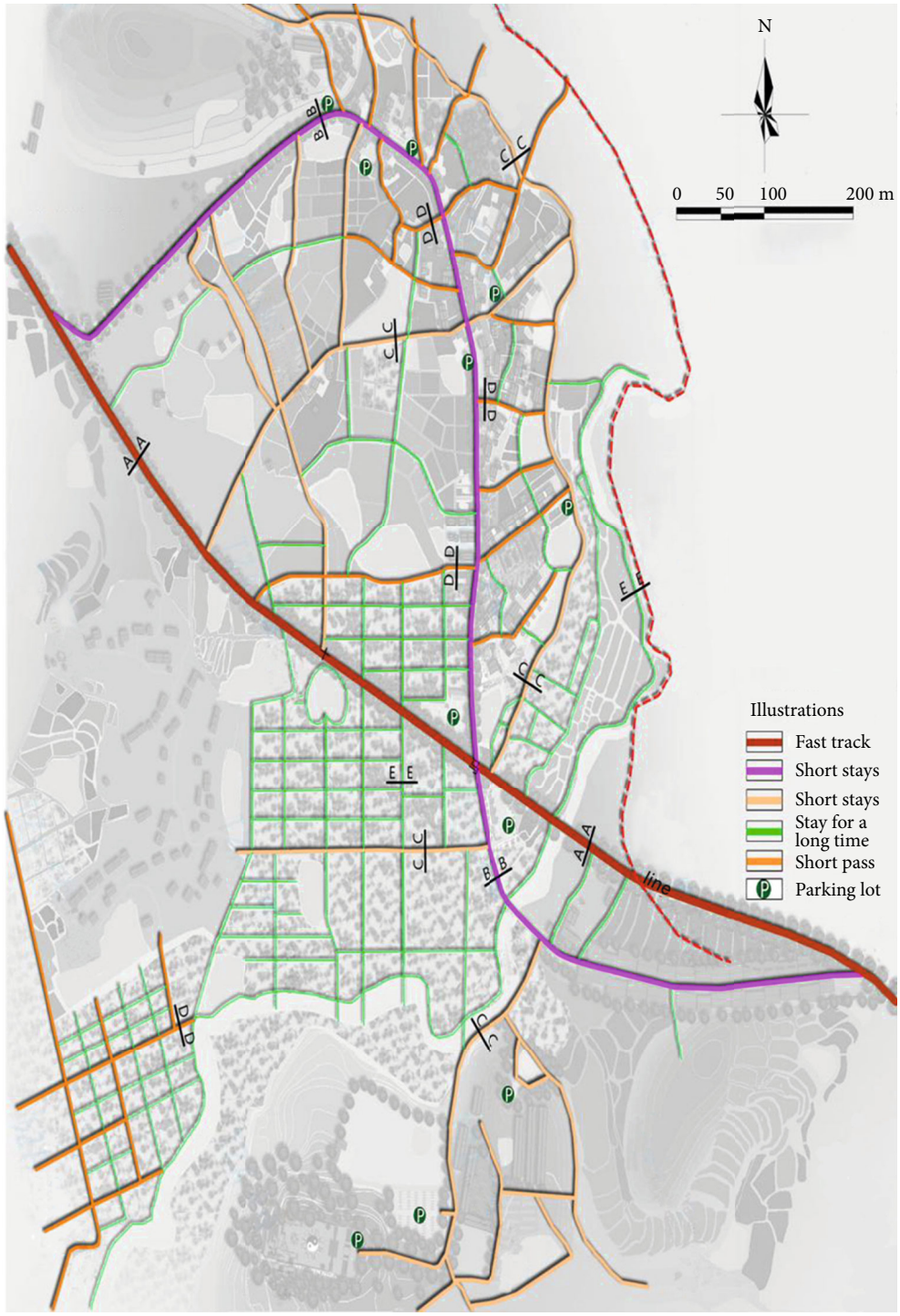

Figure 1: Map of residents' behavior patterns and stay time in Youzhaqiao Village.

the most popular attractions, and choose the one that suits their physical strength. The tour distance can improve the turnover efficiency of scenic spots [7].

6.4. Analysis Based on Age Classification and Tour Design. For the 200 behavioral trajectory data collected from tourists, by calculating the density and stay time of short time behavioral trajectories, we can get the difference in vitality and attractiveness of each spot in the village's scenic space (as shown in Table 2). We can classify visitors as young, middle-aged, and elderly. The elderly focus on and enjoy history and culture; therefore, the most frequent trajectory of the elderly is set as a cultural tour route including the space lotus cultural square, the theme exhibition hall, and the tourist tea plantations. The young and middle-aged are more interested in leisure, entertainment, and enjoyment, so the most common route for the young and middle-aged is the recreational route, which is more

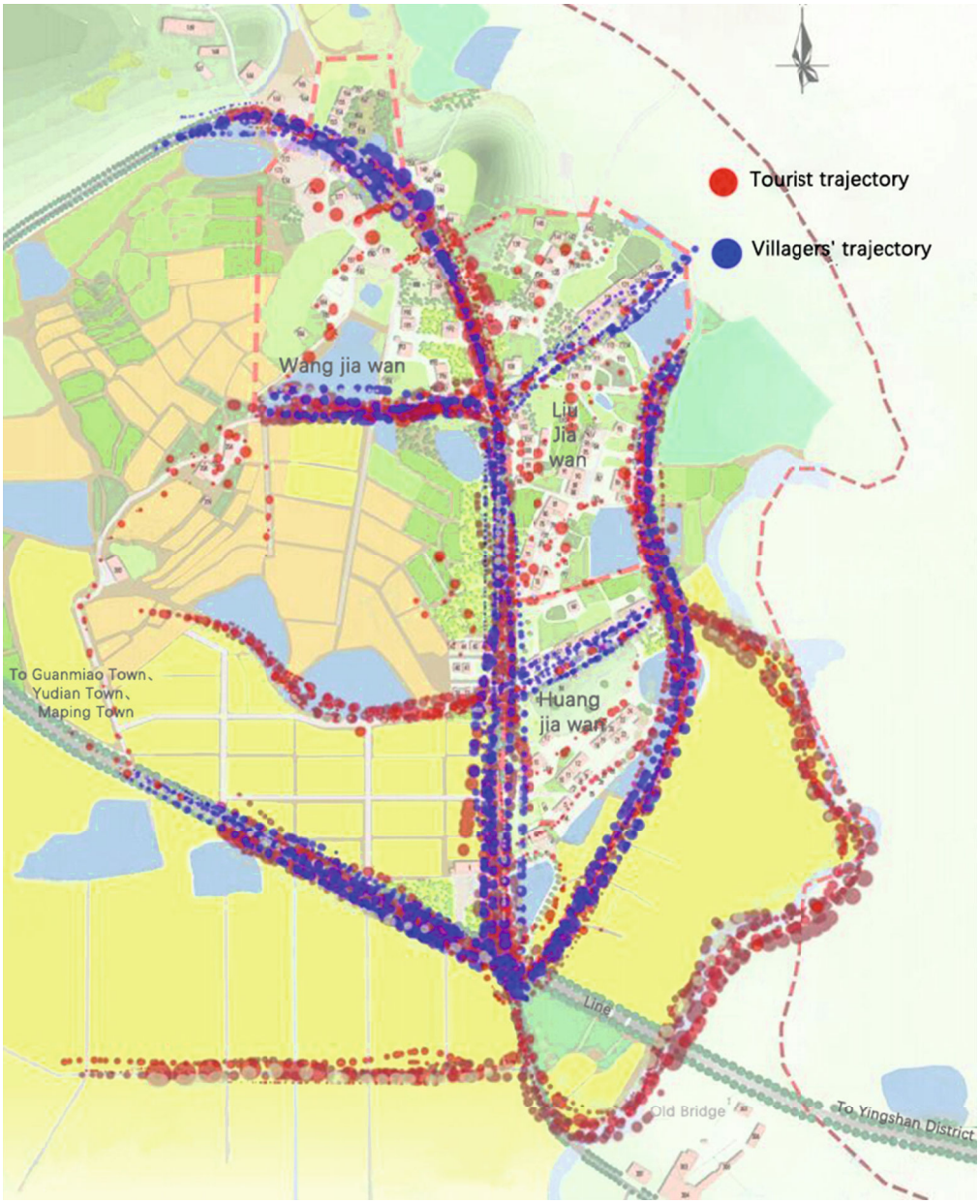

Figure 2: Map of tourists' and villagers' behavior trajectory.

inclined towards entertainment and food shopping and links the farmhouse enjoyment in Huangjiawan and Wangjiawan, the lotus-picking wharf square, vicinity of ancient Youzhaqiao bridge, the imperial city temple square, the shopping and commercial street, and the space lotus trade market (as shown in Figure 4).

6.5. Based on Behavior and Public Service Facility Evaluation Model. In this paper, residence time and supply time of public service facilities are used as two variables to measure the adaptability of regional supply and demand. Behavior trajectory data reflects the demand of tourists and combined with the superposition analysis of existing stay facilities can reflect the supply-demand relationship between this space and stay behavior (as shown in Figure 5).

(1) Determine supply levels

$$X\mathrm{ti} = \mathrm{Fi}\, T. \tag{1}$$

The supply level of stopover facilities at time t in grid I is X. Among them, the supply level of the stay facilities in the period in the first grid is the number of facilities in the first grid and the supply time of the facilities in the grid.

(2) Determine demand levels

$$Y\mathrm{ti} = (R\mathrm{ti} - S\mathrm{ti} + T\mathrm{ti}) \times T\mathrm{Ati}. \tag{2}$$

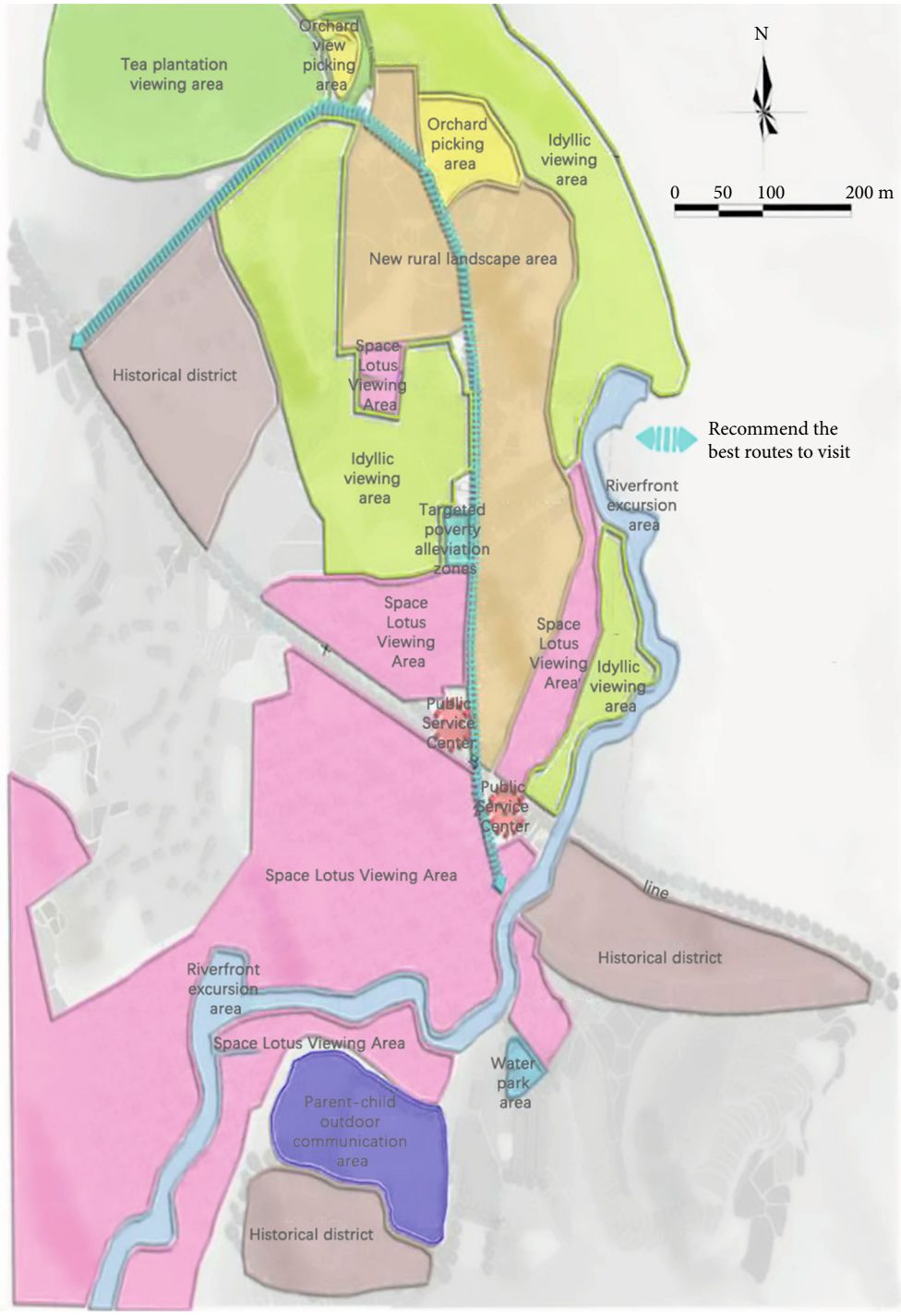

Figure 3: Recommendation of the best tour route based on analysis of trajectory data.

Table 2: Space vitality evaluation form.

	Sightseeing tea garden	Space lotus culture square	The ancient Tea Horse Road	Theme exhibition hall	Agritainment	Food shopping
Frequency	Lower	Higher	Lowest	Lower	Higher	Highest
Stay time	Higher	Lower	Lower	Higher	Higher	Highest
Overview	Landscape vitality	Lowest vitality	Traffic vitality	Higher vitality	Higher vitality	Highest vitality

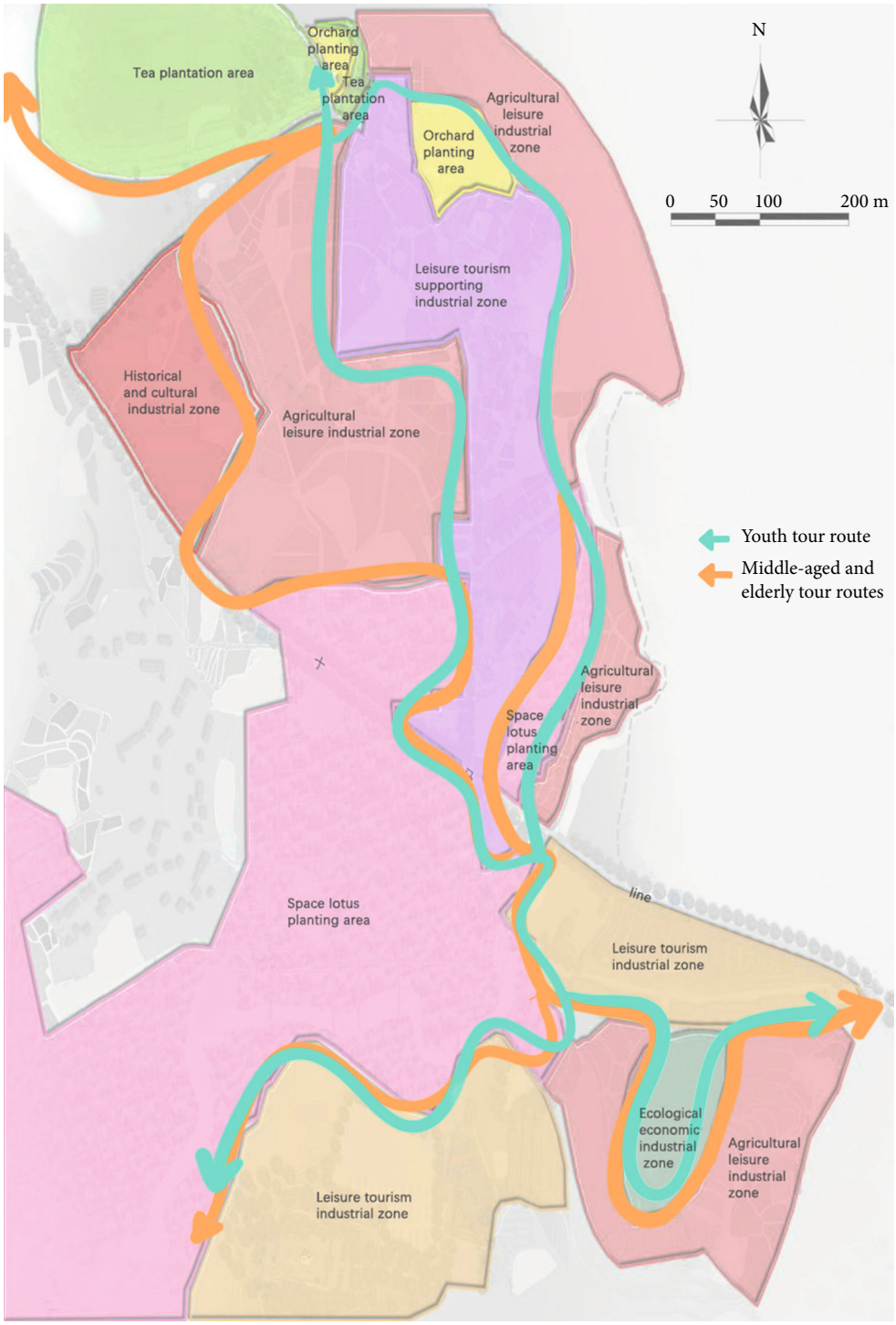

Figure 4: Recommendation of the tour route for young and middle-aged tourists based on analysis of trajectory data.

Demand level in period t in grid I is Y = (regional inflow number in period T in grid I − outflow number in period T in grid I + fixed number of people in period T in grid I) × per capita residence time in period T in grid I TAti. Among them, the demand level of the period in the first grid is the number of people flowing in the period of the first grid, the number of people flowing out of the period in the grid, the fixed number of people in the period of the first grid, and the per capita stay time in the grid period.

(3) Overlay analysis

$$Bti = \frac{Yti}{Xti} \tag{3}$$

Demand level is Yti/supply level Xti = supply − demand relationship Bti. Among them, it is the relationship between

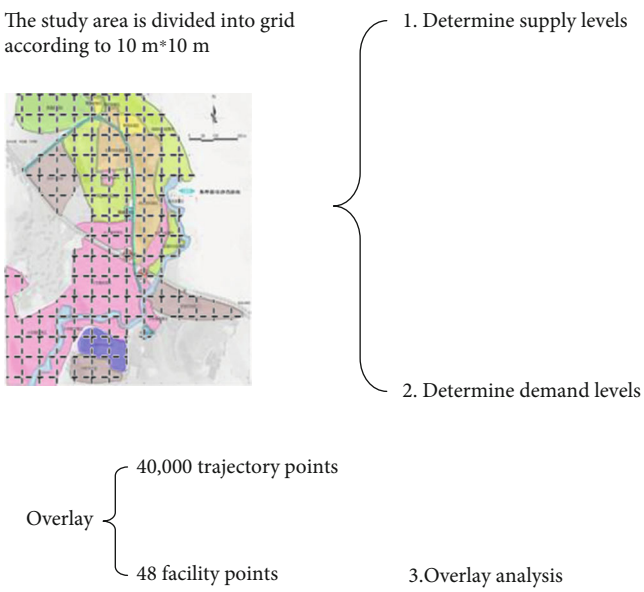

Figure 5: Grid diagram.

supply and demand, the level of demand, and the level of supply.

In essence, the balance of supply and demand is to keep a balance between the supply quantity and composition of public service facilities and the demand and composition of tourists and to provide different aspects of supply according to different needs, to seek a more harmonious and long-term development of rural tourist attractions.

According to the statistical analysis, in the areas with stopover or stopover facilities, the proportion of areas with demand greater than supply is as high as 78.6%, areas with demand less than supply account for 8.3%, and areas with good supply and demand only account for 5.2%.

6.5.1. Lack of Vitality. Excess space resources and areas where the supply of public service facilities exceeded the demand accounted for 8.3%, mainly in some areas of sightseeing tea gardens and space lotus culture square. The above areas have less people flow and few stay, and public service facilities are generally idle.

6.5.2. Rational Use. In space supply and demand balance, areas where supply equals demand account for 5.2%, mainly in space lotus culture square and theme exhibition hall. The above-mentioned area stay facilities are set appropriately to reasonably meet the needs of the crowd to stay.

6.5.3. Overload. Excessive demand for space is 78.6% of the regions where the supply is less than the demand, including theme exhibition hall, agritainment, and food shopping. Covering most of the activity areas of rural tourism scenic spots, the area has few stay facilities, which cannot meet the normal stay needs of tourists.

On the whole, the supply and demand of stay facilities in the rural core landscape area are extremely unbalanced. There are insufficient quantities, single type, and low frequency of partial use.

The optimization of the use of space stay facilities in scenic spots is mainly through reasonable adjustment of the number of public service facilities and flexible increase in the area with a large demand or by changing the composition of rural space landscape, analyzing the specific reasons for the oversupply of service facilities in areas, and guiding people to use stay facilities or transform them into other use spaces through design [8].

This paper evaluated the supply and demand status of rural spatial stopover facilities by using the GIS analysis method based on the characteristics of stopover facility layout and trajectory stay time information and provided new research ideas and design references for the characteristics of rural digital space.

Under the influence of the global spread of COVID-19 in 2020, the demand for outdoor social communication activities is increasing, which is of great significance to the spatial development of digital rural tourism [8]. In addition to meeting basic needs, it is more important to improve the spatial quality of rural digital tourism through stay facilities.

7. Conclusion

The design of the digital village space is a complex and large systematic project. Through data analysis based on the spatial-temporal trajectory data analysis in this spatial environment survey of Youzhaqiao Village, the behavioral patterns and distribution characteristics of residents and tourists can be intuitively and objectively found, and the best and most optimal routes can be recommended, providing reliable support for the design [4]. As an innovative data collection method, spatial-temporal behavioral trajectory data analysis has its advantages of realistic, real-time information and wide coverage, largely compensating for the ambiguity of traditional survey methods of collecting behavioral data and providing real-time, accurate, and rich information of various kinds, playing an important role in the space design of digital villages. Hence, the combination of trajectory data of spatial-temporal behavior and traditional survey methods will become an important approach to environmental behavior research [5].

Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflicts of Interest

The author declares that he has no conflicts of interest.

Acknowledgments

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